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MOVING THE FACTORY INTO ORBIT

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ABSTRACT

Prompted by attention focused on the Space Shuttle Program's cost and safety problems and the publicity surrounding the intended U.S.Spacestation, it seems timely to investigate the status of those efforts being made to use space as a commercial manufacturing environment.

INTRODUCTION

Orbital manufacturing requires identifying those products suitable for the space environment; the best type of production platform; the most economical launch and service arrangements; the technologies in use today that show the greatest promise for transplant to orbital application and perhaps most importantly, an evaluation of the economic impact to a nation that participates in this venture or so declines.

It should be noted that all of the written material researched for this paper was produced prior to January 28, 1986. The events of that infamous day make much of what was written seem particularly rosy in its forecasts, particularly in terms of delivering equipment into orbit, i.e. everything to be done via the Space Shuttle. The questions surfacing in the media regarding America's direction in its space program are part of this paper's topic; their final resolution should not be considered a prerequisite to making hard decisions by the U.S. industrial sector, as they will not be for our industrial competitors around the world.

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MAKING THINGS THAT ARE OUT OF THIS WORLD

There are projections that by the year 2000, a new industry will exist with sales between \$15 and \$100 billion(1). Its factories will produce products to help people live longer, healthier lives; put more powerful electronic devices in home and industry; make critical mechanical devices work better and last longer and affect other areas of our lives that few people have even thought of yet! It will be pollution free, environmentally safe and its growth will spur other industries to develop complimentary "spin-off" products. This sparkplug of 21st century technology is space manufacturing.

The space environment, for all its hostility and the difficulty of getting there, presents unique conditions that cannot be reproduced anywhere on earth. Its three major conditions are microgravity, vacuum isolation and extreme temperatures. Solar panels can be made very large and increasingly efficient solar cells can produce large quantities of "free" power to keep orbital factories going. Table I below details those materials for proposed space manufacture that take advantage of these particular conditions.

Table I
Feature/Product Benefit Relationships

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|---|--|
| Microgravity/ Freedom from Vibration | <ul style="list-style-type: none">- Pharmaceuticals (electrophoresis)- Pure crystal and film growth- Containerless material processing |
| Vacuum Isolation | <ul style="list-style-type: none">- recombitent DNA research (safety considerations)- contamination free environment for many different processes |
| Extreme Temperatures | <ul style="list-style-type: none">- metalurgical alloy processes- crystal growth- molecular physics research |

All of these products have in common that they are small, difficult or impossible to produce in quantity on earth and often for reasons of human safety, require expensive manufacturing facilities on earth. The space environment suites their special manufacturing requirements to a "T".

THE SHAPE OF THINGS TO COME

Discussing an Orbiting Manufacturing Facility is a little like talking about cars; it's a generic term. Different types fit different needs. To date, experiments have been conducted aboard the Space Shuttle, the ESA Spacelab that rides in the shuttle

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payload bay and even as far back as Skylab in the American space program. The Soviet Union has been conducting material processing experiments for 10 years on Salyut space stations and to date has performed over 1500, while the U.S. has done about 100 (2). These facilities have been small, experimental devices not designed to produce sufficient quantity of product to allow for commercialization. These one-shot manufacturing sessions have also been limited by the length of the shot, at least in the case of the U.S. space program. Shuttle missions last only as long as a week, insufficient time to fine tune a process or produce economic quantities of a product. What the Soviets may have actually done is unknown, but Salyut crews have been in space for many months at a time, overcoming the drawbacks we've had to face.

James Samuels, First VP of Research at the financial firm Shearson Lehman Brothers in New York City has stated: "What's lacking in materials processing in space is the factory. Experiments on the Shuttle are of small magnitude, producing only small quantities of material. Until a large enough space facility to produce large enough quantities of materials is available, it's difficult to see how materials processing in space could be an ongoing business (3)." Lately, the trend seems to be focusing on the proposed U.S. Spacestation as the means for any future space activity. A Stamford University researcher, pushing for increased commercial interest in space, observed: "It seems odd that we're working on (building) unmanned factories on Earth while saying we need people for manufacturing in space (4)." A material scientist at 3M Company's R&D group views the proposed Spacestation as designed for R&D only, using space as an environment for doing science *FT1*. Others agree that NASA should focus its efforts and attention on exploration and basic research and development. Another important consideration is the very high cost of putting and keeping men in space, considerably higher than automated spacecraft. This combination of requirements and restrictions seems to be driving the need for advanced free-flying platforms, and not too surprisingly that is the direction both ESA and a private American firm are leaning. Originally scheduled for launch in 1987, EURECA (for European REusable Carrier) is an extension and enhancement of the SPAS (Shuttle PALlete Satellite) system put into orbit and retrieved on STS-7 in June 1983 (5). The EURECA satellite would stay in orbit about six months after being placed there by the Shuttle, and would thus be retrieved after spending that time in materials processing. More ambitious is the Industrial Space Facility as designed and built by Space Industries Inc.. This vehicle also would be placed in orbit by the Shuttle, but unlike EURECA, it is fully enclosed and pressurized for human occupation. Once checked out and set-up, the mission specialist will leave, the ISF will be detached from the Shuttle and left as an automated free flyer. It will be visited by future shuttle flights which will attach new supply modules, recover processed material, make any specialist-required adjustments or repairs and then be left again to do more processing (6).

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The vehicle is still being developed with a launch schedule for the early 1990's. Time to make modifications due to relevant launch vehicle costs and availability considerations is soon running out. What can be done here to "boost" the economics of space processing?

GETTING THERE IS HALF THE CHALLENGE

Of immediate concern to everyone involved with American space exploration and use is the current (8/1/86) unavailability of any launch vehicle deemed safe and operational. The consecutive failures of the Space Shuttle, the Air Force Titan 34D and NASA's Delta launch vehicle have sent many, both in the U.S. and abroad, rethinking their strategy for the use of space. The realization that once the Shuttle does become reoperational it will be largely dedicated to military payloads for almost two years has stunned the civilian space community. A great deal of evaluation is still going on for the when-and-where to use the Shuttle versus expendable launch vehicles. In addition, the questions are raised about a private contractor going into the space launching business by renting NASA's existing facilities. Along these lines, it's been proposed that the enhanced Titan 34D7, which is being built for the Air Force, be made available to private purchasers with all the line start-up and development costs being paid by the Air Force. The noteworthy feature of the Titan 34D7 is that its payload configuration and capability closely match that of the Shuttle. In the free market's hands, the "business" of launching business satellites, whether communication or manufacturing, would become more price competitive with French Ariane, especially the Ariane III which has a larger payload capability similar to the Titan 34D7. Also to be considered is the up-and-coming space launch capability of the Japanese and the Chinese. Even the Soviet Union is loosening up its bonds of secrecy to court its substantial launch capability to the world market. Run as a business venture, launch costs could begin to drop from the \$5000 per pound they are now with the Shuttle toward the long dreamed of \$100 per pound predicted in the mid-1970's. If costs could be substantially reduced, the number of products that may be economically manufactured in orbit could easily triple *FT2*. Under such a coherent industrial space policy, only scientific satellites and the Spacestation itself need be placed in orbit by the Shuttle. Both military and industrial satellites would be launched by mass-produced, expendable launch vehicles. The Shuttle's ongoing use would be the servicing, repair and/or recovery of satellites already in orbit when the need for manned observation and activity could not be replaced by automation.

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MAKING (THINGS) DO (MORE)

The Factory of the Future is a term that's been used in the Instrumentation & Control marketplace for 5 or so years now here on earth. It describes a workplace that is sparsely populated by human workers but rather is highly automated, very precise in the quality of its products, capable of adapting to changing environmental considerations and requiring only routine servicing by its human operators. This goal has been the driver for bringing new technology to market and generating spinoff products into many other markets. For example, the development of the microprocessor has meant that large complex electronic measurement and control products have been reduced in size and cost with corresponding increases in features and operating life. As the demand for greater sophistication in microprocessors grew, new uses were found for the older micros; now microwave ovens, televisions, VCR's and sewing machines have benefitted from capabilities that were once available only in industrial devices. As more uses were sought for these advanced microprocessors, a whole industry sprang up around "personal computers". The list of such products goes on.

The microprocessor of 8 years ago is growing into the microcomputer of today, and it along with several other state-of-the-art manufacturing trends would be most applicable to the needs of a space manufacturing system. The microcomputer is the cornerstone to the world of minaturization needed to package a complex factory into 2500 cubic feet, or less. Figure I shows a currently available industrial controller with I/O interface modules to the process itself. Such a device, occupying but 0.25 cubic feet could control an entire process at a cost of under \$5000 (7).

Knowing how to respond to modified production procedures, changing environmental considerations or unscheduled equipment shutdowns is typically a "man's" job. But there won't be any men in free-flying manufacturing facilities like those described earlier. Having the "smarts" to deal with changing conditions is no longer only in the realm of human operators, but is becoming available in artificial intelligence, or "Expert" control products. Figure II shows a device for controlling a process loop that, instead of solving a conventional second order equation to adjust a final control element, uses over 200 IF/THEN rules to establish pattern recognition techniques for individual loop control. This product represents the first such device in the industrial marketplace that has taken the fledgling science of Artificial Intelligence from the chessboard onto the shop floor (8).

Another recently introduced industrial product is a certain type of I/O device that can be programmed to be either an input or an output. The electronics on board the device are capable of either driving or receiving current, unique in the industry.

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In addition, the device has built in diagnostics that report back to the central controller the nature of any failures that occur in the device (9). An extension of this technology could allow for a central controller on a free-flying station to reconfigure the instrumentation on board in event of a failure, so continuous processing would not be interrupted. The final new "technology" to be discussed here is not a piece of hardware at all, but rather a design philosophy that works by using all of the above technologies to some degree, coupled with mechanical robotics. It's call Flexible Manufacturing Systems. What it says is, instead of designing a production line to mass produce a single part or item, put small, intelligent, reconfigurable controllers at each station along the line; give each station the ability to do many different things; even give the line itself the ability to redirect the flow of material from start to finished product, skipping stations not needed to make product X, returning several times if required for product Y. This method of built-in flexibility eliminates the need for any retooling to make changes in a product, or to go from one product to another. The result is a production facility that can make small runs of a given part, or even just one unit of a given part, and most importantly, be competitive with large, dedicated production lines. Such a situation can be found at a Rockwell International plant making parts for the B-1B bomber. Flexible Manufacturing has started to find a niche in what are traditionally viewed as machine tool industries, i.e. industries where things are machined, not where stuff is processed. In the process industries, the term batch processing describes the condition where a given amount of product A (cookies) is produced, then equipment is reset (cleaned), reprogrammed (new receipe) and another product is produced (muffins). Much attention has been paid to batch processing in recent years as two diverse technologies, discrete and continuous control, have started overlapping. Control systems touted as Batch Controllers have come to market. At present, batch control devices remain more than anything else a single box with two, still separate technologies shoe-horned inside. This brings up the final point to be made in the case of space manufacturing.

THE GIVE AND TAKE

"The frontier of space should be a driver for new technology" is the first thing I was told by one space manufacturing advocate FT3. It certainly is for weapons technology as being developed for the Strategic Defense Initiative (SDI or Star Wars research as it's more commonly referenced). The field of space manufacturing would also be a driver for reusable, transportable technology here on Earth; not to mention the day to day benefits of products actually made in orbit. In the earlier days of the space program, spinoff products were easily identified by their use in the space program. Teflon and Velcro will be forever immortalized for bringing the space age into the home more so than televised lift-offs!

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The color camera, smaller than a shoe-box, used on the moon by Apollo 12 astronauts cost tens of thousands of dollars. Today anyone can film their kids splashing in a pool with a color video camera that costs about \$600 and is functionally the same thing. Redundant computers on the Space Shuttle, and the voting algorithms in software that make them work together, have been transported to industrial controllers over the last few years: the calculated mean time between failures (MTBF) - over 300 years. Even the solar cells used to power communications satellites now show up on watches and calculators.

Consider a few of the products that could be readily made in quantity in space and some specific applications: composite alloys could be perfectly manufactured that have an operational life expectancy many times that of any earth-manufactured. How much more valuable will the machines incorporating these be? In space, gallium-arsenide crystals can be grown that can be used for denser and faster micro-chips. With the extremely competitive nature of the world computer industry, what impact would it have for the company that had a computer with orders of magnitude greater speed, memory and operating life versus any of its competitors? Of most serious concern, what if these products were only available from the Japanese, the Germans or the Soviet Union? What can happen if technology transfers do not take place from Space to Earth is pointed up by this example. The Soviet space program has perfected for several years now sending Progress robot resupply ships to automatically dock with orbiting Salyut space stations; no mean feat! Yet, when they experienced the problem at the Chernobyl nuclear plant earlier this year, the Soviets borrowed a robot from West Germany to go inside the damaged plant to observe its condition. The need to go to an outside source for such technology is evidence of the failure in the Soviet economic system to promote the transfer of technology from one segment of its economy to another. The U.S. is not free from guilt here either. Witness the video technology described earlier: perfected by a need in the U.S. space program 16 years ago, advanced video equipment used in this country today is almost exclusively made overseas. Consider this scenario: super-dense gallium-arsenide computer chips become commercially available through an orbiting manufacturing facility. They are then etched with not one, but three complete microcomputers complete with enough permanent memory to contain a complete redundant (voting) operating system. The resultant product would be a microcomputer with an operating life of not thousands of hours, but hundreds of years, and would fit in the palm of your hand! Such a device implanted in control and measuring equipment here on earth could revolutionize the reliability aspect of industrial products. And if all such available products say "made in Japan" the U.S. instrumentation industry could be in big trouble.

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The initial product, made in space, forged together with the technology used to build space capable hardware would produce an end result that would stand in a class by itself, unreproducible, since the heart of the device is a substance that's available in only one place.

To catch up would require years of effort while revenues were being lost to this unique competitor.

Space based industry will be a new way of life so says Dr. Roald Zagdeev of the Soviet space program (10). It will be so for everyone as the next century dawns--it will be for good or bad based on decisions made by U.S. companies, the U.S. government and other interests around the world. These decisions are being made now, with billions of future dollars riding on them.

CONCLUSION

The methods are still under development, the costs need to come down and interest needs to be rekindled in light of recent failures of launch vehicles, but space manufacturing is an enterprise on the near horizon that those closest to it are sure will be worth billions of dollars by the end of this century. Viewed as a technology driver, it appears to be the greatest non-military effort for its world-wide participants to sharpen their competitive edge in many fields of science and engineering. It is a swinging door for industry, allowing advanced production schemes to be enhanced and used "up-there" while transporting what's developed into spinoff products "down-here". Though any financial rewards must be considered long term at this point, it appears that short-sightedness on any nation's part could easily lock it out of marketplaces yet to be tapped 10, 15 and 20 years from now. For the benefit of the future U.S. economy, a coherent industrial policy for the use of space, from launch vehicles to licensing agreement, needs to be developed.

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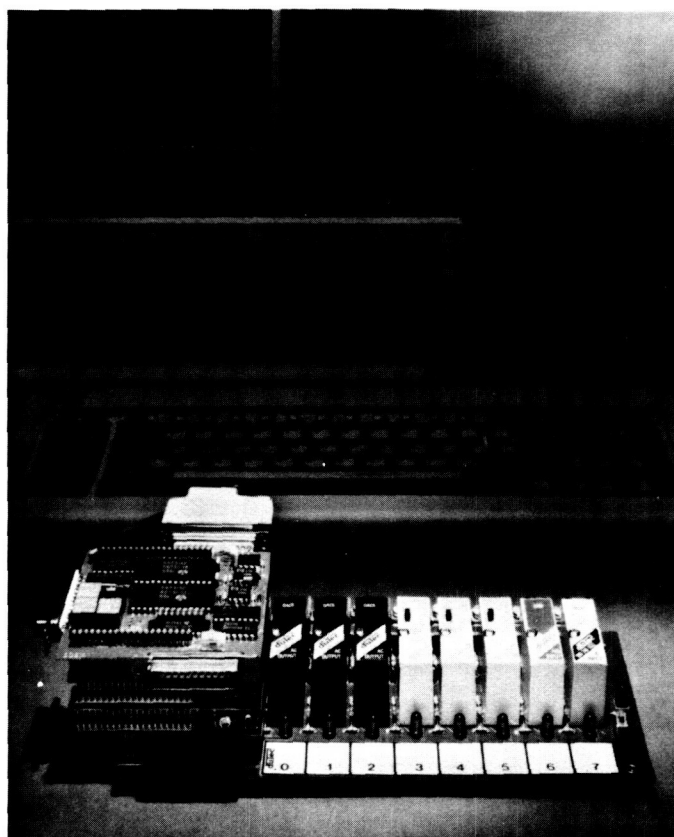


Figure 1. Programmable controller for process applications from duTec (courtesy of duTec Company)

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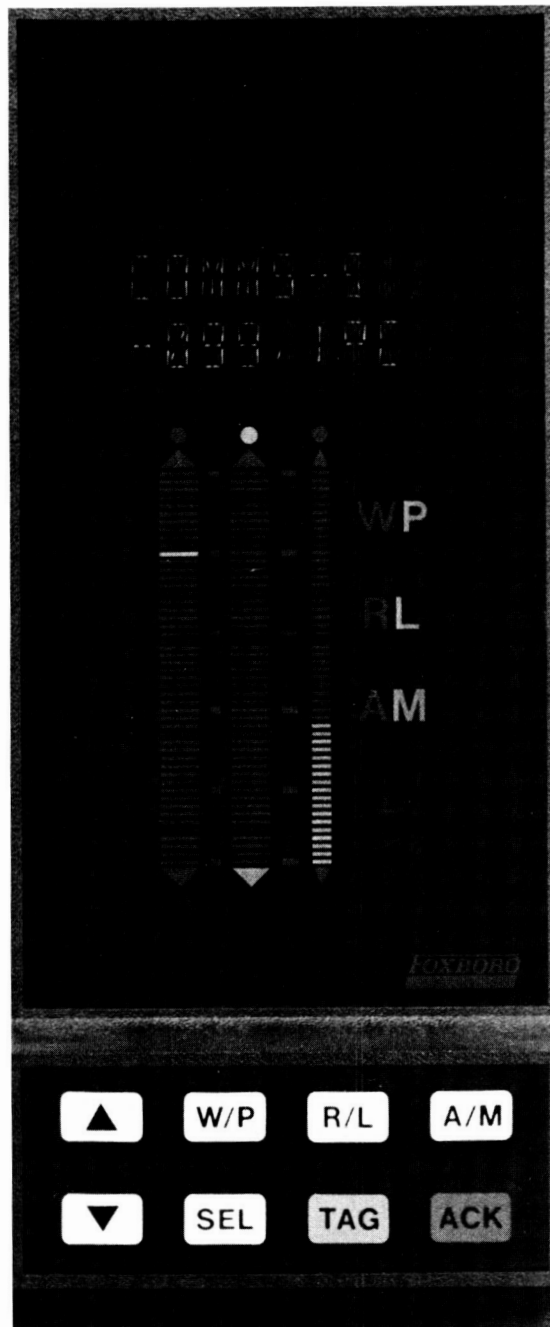


Figure 2. Single loop process controller with artificial intelligence algorithms for closed loop control. (courtesy the Foxboro Co.)